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NEUTRON ACTIVATION ANALYSIS OF BOTTOM SEDIMENTS

Robert V. Moore, et al

Environmental Protection Agency
Athens, Georgia

March 1973

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Neutron Activation Analysis of Bottom Sediments

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Elements readily analyzed are Al, As, Ba, Mg, Dy, Mn, V, Cr, Co, Fe, La, Sb, Br, Cl, Au, K, Sm, Se, Na, Th, and Ti. (EPA)

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NEUTRON ACTIVATION ANALYSIS OF BOTTOM SEDIMENTS

by

Robert V. Moore
Oliver W. Propheter
Southeast Environmental Research Laboratory
College Station Road
Athens, Georgia 30601

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ABSTRACT

Instrumental neutron activation analysis (INAA) was applied to bottom sediments obtained from 17 locations (small and large rivers, a canal, coastal waters, and a bay) within the United States to determine the applicability of INAA to water pollution studies. Irradiations of 30 seconds and 60 minutes, followed by three pulse-height analyses of gamma radiation, detected and measured up to 43 elements including most elements of interest. Decay times did not exceed seven days. Sample handling was minimal.

Elements readily analyzed are Al, As, Au, Ba, Br, Cl, Co, Cr, Dy, Fe, K, La, Mg, Mn, Na, Sb, Sm, Th, Ti, and V.

Elements that could be analyzed, but for which optimum conditions of analysis (length of irradiation, time of decay, time for counting, and type of detector) were not used, were Ag, Ca, Cd, Ce, Cs, Cu, Eu, Hf, Hg, I, Lu, Mo, Nd, Rb, Se, Sr, Te, U, W, Yb, and Zn.

At least 30 elements can be determined in duplicate for about $120 per sample with optimum laboratory utilization and number of samples.

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SECTION I

CONCLUSIONS

Sediment analysis using INAA is practical, sensitive, and, for many elements, the method of choice. As improvements in instrumentation occur, the applicability will be extended.

SECTION II

RECOMMENDATION

Instrumental neutron activation analysis should be used to determine elemental composition of sediment samples when consideration of sensitivity, selectivity or economy indicates it to be practical. Computerized data analysis should be used for multielement analysis.

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SECTION III

INTRODUCTION

Many water pollutants are associated with bottom sediments either directly or by adsorption on soils. Bottom sediments are not always inert but are often reservoirs from which pollutants that are leached or taken up by microbiota enter the food chain.[1] Comprehensive elemental analysis of bottom sediments is necessary to assess the significance of and to determine the fate of adsorbed pollutants. Complexity of sample matrices and uncertainty of sample stability during preparation present significant problems in the application of other conventional techniques which must use destructive techniques in the preparation of samples for analysis.

Bohannon *et al.*[2] demonstrated the overall applicability of instrumental neutron activation analysis (INAA) to water pollution studies but did not include sediments. They analyzed for only six elements using a NaI(Tl) crystal scintillation detector. The solid-state germanium detectors, Ge(Li), used presently extend the use of INAA to many more elements as demonstrated by Dams *et al.*[3], who analyzed for 33 elements in air particulates. De Groot *et al.*[4] demonstrated the applicability of INAA to river sediments by analyzing for 10 elements and noting the presence of 15 others.

Reported are instrumental neutron activation analyses of 18 sediment samples collected from 17 regions within the United States. Analyses were performed at the Southeast Environmental Research Laboratory (SERL), Nuclear Analysis Facility located at the Nuclear Research Center, Georgia Institute of Technology, Atlanta, Georgia.

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SECTION IV

EXPERIMENTAL

Eighteen samples of bottom materials, selected to be representative of a wide variety of silts and sediments, were collected from rivers, a canal, coastal waters, and a bay. The samples were packaged in glass jars or polyethylene bottles with enough water to insure that they were moist when received by the National Bureau of Standards (NBS). The analyses performed at NBS[5] were used for comparison in this report.

Aliquots of the sediments were forwarded to SERL in glass containers with sufficient water to keep them moist. Portions of the samples were placed on filter paper, and the excess water was allowed to drain before they were placed in all-glass containers. The resultant moisture content was determined by weighing a separate portion of the wet sample, drying overnight at 110°C, then reweighing. Wet samples to be irradiated in the nuclear reactor weighed from 0.1 g to 0.9 g.

Portions of each sediment were irradiated in the nuclear reactor: one for 30 seconds to determine elements with short half-lives, and another for 60 minutes for longer lived elements. The portions to be irradiated for 30 seconds were placed in $^2/_5$-dram polyethylene vials and heat sealed. After irradiation, a portion of the irradiated material was transferred into another clean, tared, $^2/_5$-dram vial and weighed. The flux monitor, consisting of an aliquot of a standard arsenic solution, was treated similarly. This permitted radioactive argon to escape and removed the interference from activated elements in the irradiated vial itself. Only one sample and its flux monitor were irradiated at a time because the short half-lives did not allow enough time to do more.

Samples to be irradiated for 60 minutes were weighed into quartz vials and heat sealed. Flux monitors, again of standard arsenic solution, were treated similarly. Three samples and a flux monitor were irradiated together. After an appropriate waiting period each sample was counted in its vial without further treatment.

All samples were introduced into the nuclear reactor via a pneumatic tube system and were irradiated at a thermal neutron flux of $10^{13} n/cm^2/sec$.

The gamma emissions of each 30-second sample were analyzed and counted after an elapsed time of about 10 minutes and again after about 100 minutes. The delay was predicated by the activity of the sample. The sample was placed in a position calibrated for

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geometry effects within a shield with the dead time of counting no more than 25%. (Dead time is the time the detector is shut down while detected gamma photons are processed.) Counting times of either 200 or 400 seconds were used depending on the need to obtain statistically valid counts for minor constituents. Data were typed out only for the elements of interest because a complete typeout would have taken too much time. The flux monitor was counted after the 10-minute count and prior to the 100-minute count.

The 60-minute irradiation samples were stored behind 4 inches of lead for a period of 6 or 7 days prior to gamma analysis and counting for 2000 seconds. The requirements of position and dead time given above were obeyed. All data were printed out so that a complete qualitative and quantitative analysis could be made. The flux standards were counted at times comparable to the samples.

Quantitative standards for each element were irradiated along with their flux monitors for the appropriate time of irradiation. These standards were counted in the same manner as the unknowns. All results of gamma counting were normalized back to the time of irradiation for a standard counting period. Flux monitors made the direct comparison between standards and unknowns possible by correcting for differences in flux. Corrections for dead time and geometry were also made.

Qualitative analysis was made by comparing primary peak energies obtained from data output with theoretical energies. Very little interference exists in naturally occurring samples, and when it does, it can readily be resolved by utilizing secondary peaks.

Quantitative analysis was also based on primary peaks. Only in a few cases was it necessary to use secondary peaks. Peak counts corrected for background, dead time, and geometry were normalized to the end of irradiation for a counting time of 200 seconds. Count rates for unknowns were compared to standards adjusted for flux. Concentrations were obtained in grams of element per gram of dry sediment.

The detector used was a large Ge(Li) solid state detector with an efficiency of 9.85% compared to a 3 x 3 inch NaI(Tl) scintillation detector. It had a resolution of 2.12 keV full width half maximum (FWHM) for the ^{60}Co 1332 kev photopeak and a peak-to-Compton ratio of 32:1. The analyzer was a Nuclear Data 2220 multichannel analyzer system with an analog-to-digital converter resolution of 4096 channels and a 1024 channel memory. With a calibration of 1 kev per channel, two multichannel analyses had to be made per sample: from 0-1024 keV and from 1025-2048 keV. This was done

for each sample and for each time of radiation. As there were no elements of interest with gamma energies greater than 2048 keV, no further multichannel analyses were made.

SECTION V

RESULTS AND DISCUSSION

Table 1 shows the results of the 30-second irradiations along with the NBS data for comparison. Table 2 shows the 60-minute irradiation data along with the NBS data for comparison. NBS analyzed the samples for all the elements reported by emission spectroscopy and for five elements by INAA.[5] The results given in both Tables 1 and 2 are in quantitative agreement consistent with the analytical uncertainties and evident heterogeneity of the samples. The exceptions to this are mercury, copper, and barium.

Values for mercury cannot be compared. Some samples were collected in polyethylene bottles and NBS irradiated samples in polyethylene vials. Mercury is lost from polyethylene containers during storage[6] and irradiation.[7] The samples affected and the extent of loss are not known.

Copper values reported by SERL are probably high. The original activity of the total sample was very high. In the time it took for the sample to decay so that the dead time was less than 25%, copper had decayed through 11 half-lives. Copper is quantitated using the annihilation peak at 511 kev. A number of other elements, including zinc and europium, make small contributions, usually negligible, to this peak; however, after 11 half-lives of decay for copper, the contributions from other sources with long half-lives becomes significant.

SERL barium values are lower than those of NBS. Barium was quantitated by each of two isotopes, 131 and 139, with comparable results.

In addition to the elements quantitated, the following elements were also detected in one or more samples: Ag, Au, Br, Ca, Cd, Ce, Cl, Cs, Dy, Eu, Hf, I, K, Lu, Mo, Na, Nd, Rb, Sc, Se, Sm, Te, Th, Ti, U, W, and Yb. Many were in all samples and many could have been quantitated.

In sediment samples a number of elements can readily be analyzed by the method described because their concentrations are so large that their detection limits are not approached. These elements include: Al, As, Ba, Br, Cl, Co, Cr, Fe, K, La, Mg, Mn, Na, Sc, Sb, Sm, Ti, and V.

The procedure described is not optimal for some elements. For example, a shorter irradiation followed by a relatively shorter

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decay period would have given better values for Cu. A number of other elements could have been quantitated better if a longer counting time had been used. A longer decay time before counting, allowing short and intermediate half-life elements to die out, would, of course, have optimized the counting of long half-life elements. The variables of irradiation time, decay time, and counting time could have been varied to optimize conditions for analysis for the elements Ag, Au, Ca, Cd, Ce, Cs, Cu, Eu, Hf, I, Mo, Nd, Rb, Se, Sr, Te, Th, U, W, Yb, and Zn.

Low-energy photon detectors (LEPD) have become available to complement the large Ge(Li) detectors. These LEPD are also Ge(Li) detectors but are thin, which causes them to be more efficient and have much better resolution at energies below 200 keV than the standard high volume Ge(Li) detectors. Also, the Compton backscatter of high energy gamma photons is minimized on the LEPD. These two factors make the LEPD ideal for the analysis of elements such as Hg with its 77.6 keV gamma emission. Other elements that could ideally be analyzed using a LEPD are: Ba, Br, Cd, Co, Dy, Eu, Gd, Ho, Mo, Nd, Th, Se, Sm, Sr, Ta, Te, Th, U, and W.

A dedicated computer would permit the analyst a greater latitude in selecting optimal conditions for INAA, and would increase the range, sensitivity, and accuracy of analysis. It would also decrease the time factor so that INAA could compete favorably with other analytical procedures. Through the use of good detectors, fast multichannel analyzers, and proper dedicated computers, optimum numbers of sediment samples could be analyzed in duplicate, quantitated for 30 elements, with qualitative analysis for up to 60 elements, for about $120 per sample.

SECTION VI

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Table 1 Quantitative Analysis of Samples Irradiated 30 seconds

Element	^{28}Al		^{76}As			^{139}Ba		^{27}Mg		^{56}Mn			^{52}V		
Laboratory / Method / Sample	SERL	NBS	SERL	NBS		SERL	NBS	SERL	NBS	SERL	NBS		SERL	NBS	
	NAA	ES	NAA	NAA	ES	NAA	ES	NAA	ES	NAA	NAA	ES	NAA	NAA	ES
37913	4.0×10^{-2}	10^{-2}	3.6×10^{-5}	1.1×10^{-2}	10^{-3}	3.4×10^{-2}	10^{-2}	1.0×10^{-1}	10^{-2}	1.1×10^{-3}	1.4×10^{-3}	10^{-4}	5.4×10^{-5}	5.4×10^{-5}	
37914	2.5×10^{-2}	10^{-3}		2.8×10^{-3}	10^{-3}	6.0×10^{-2}	10^{-2}	6.4×10^{-2}	10^{-2}	4.1×10^{-4}	4×10^{-4}	10^{-4}	4.6×10^{-5}	2.1×10^{-5}	
37915	4.4×10^{-2}	10^{-2}		2.3×10^{-5}		4.8×10^{-4}	10^{-3}	5.0×10^{-3}	10^{-3}	7.9×10^{-4}	7×10^{-4}	10^{-4}	3.2×10^{-5}	5.0×10^{-5}	
37916	9.2×10^{-2}	10^{-2}		2.4×10^{-5}		7.7×10^{-4}	10^{-3}	8.1×10^{-3}		2.4×10^{-4}	4×10^{-4}	10^{-4}	5.4×10^{-5}	$<1\times10^{-5}$	
37917	6.5×10^{-2}	10^{-2}		3.9×10^{-5}		9.1×10^{-4}	10^{-3}	9.7×10^{-3}		8.6×10^{-4}	1.1×10^{-3}	10^{-4}	5.3×10^{-5}	1.1×10^{-4}	
37918	8.1×10^{-2}	10^{-2}		1.5×10^{-5}		8.4×10^{-4}	10^{-3}	1.1×10^{-2}	10^{-3}	5.5×10^{-4}	9×10^{-4}	10^{-4}	6.1×10^{-5}	1.2×10^{-4}	
37919	4.0×10^{-2}	10^{-1}		3.3×10^{-5}		5.4×10^{-4}	10^{-3}	2.1×10^{-2}	10^{-2}	9.0×10^{-4}	1.1×10^{-3}	10^{-4}	3.6×10^{-5}	8×10^{-5}	
37920	5.3×10^{-2}	10^{-1}		$<2\times10^{-5}$		4.8×10^{-4}	10^{-3}	8.6×10^{-3}	10^{-3}	6.5×10^{-4}	9×10^{-4}	10^{-4}	4.8×10^{-5}	1.0×10^{-4}	10^{-4}
37921	5.8×10^{-2}	10^{-1}		1.5×10^{-5}		6.4×10^{-4}	10^{-3}	3.3×10^{-3}	10^{-3}	1.4×10^{-3}	2.1×10^{-3}	10^{-4}	3.0×10^{-5}	$<1\times10^{-5}$	
37922	8.2×10^{-2}	10^{-1}		$<4\times10^{-5}$		3.9×10^{-4}	10^{-3}	4.6×10^{-3}	10^{-3}	1.6×10^{-4}	2×10^{-4}	10^{-4}	7.6×10^{-5}	1.1×10^{-4}	10^{-4}
37923	5.6×10^{-2}	10^{-1}		1.0×10^{-5}		4.9×10^{-4}	10^{-3}	3.0×10^{-3}	10^{-3}	8.2×10^{-4}	9×10^{-4}	10^{-4}	5.9×10^{-5}	9×10^{-5}	
37933	9.6×10^{-2}	10^{-1}		1.3×10^{-5}		1.1×10^{-3}	10^{-3}	8.1×10^{-3}	10^{-3}	1.4×10^{-3}		10^{-4}	8.6×10^{-5}		
37934	1.0×10^{-1}	10^{-1}		$<4\times10^{-5}$		4.3×10^{-4}	10^{-3}	1.1×10^{-2}	10^{-3}	3.9×10^{-4}		10^{-4}	7.9×10^{-5}		
37935	4.1×10^{-2}	10^{-2}	1.3×10^{-5}	1.1×10^{-5}		4.7×10^{-4}	10^{-3}	6.4×10^{-3}	10^{-3}	6.0×10^{-4}		10^{-4}	2.6×10^{-5}		
37936	1.2×10^{-1}	10^{-2}	1.6×10^{-5}	$<3\times10^{-5}$		2.6×10^{-4}	10^{-3}	3.1×10^{-3}	10^{-3}	4.2×10^{-4}		10^{-4}	1.7×10^{-5}		
37947	6.1×10^{-2}	10^{-3}				5.7×10^{-4}	10^{-3}	1.8×10^{-2}	10^{-2}	4.0×10^{-4}		10^{-3}	7.3×10^{-5}		10^{-5}
37950	6.6×10^{-2}	10^{-2}				9.2×10^{-4}	10^{-3}	8.4×10^{-3}	10^{-1}	4.9×10^{-4}		10^{-3}	3.9×10^{-5}		10^{-5}
37961	6.8×10^{-2}	10^{-3}				1.3×10^{-3}	10^{-3}	2.4×10^{-1}	10^{-2}	4.0×10^{-4}		10^{-3}	6.3×10^{-5}		10^{-5}

LEGEND

All values g element/g dry sed.
SERL - Southeast Environmental Research Laboratory
NBS - National Bureau of Standards

NAA - Neutron Activation Analysis
ES - Emission Spectroscopy
ND - Not Detected

Table 2 Quantitative Analysis of Samples Irradiated 60 minutes

Element	^{76}As			^{131}Ba		^{51}Cr		^{60}Co		^{64}Cu		
Laboratory	SERL	NBS		SERL	NBS	SERL	NBS	SERL	NBS	SERL	NBS	
Method / Sample#	NAA	NAA	ES	NAA	ES	NAA	ES	NAA	ES	NAA	NAA	ES
37913	3.3×10^{-3}	1.1×10^{-3}	10^{-3}	4.8×10^{-3}	10^{-2}	9.7×10^{-4}	10^{-4}	3.0×10^{-5}		3.1×10^{-3}	1.6×10^{-3}	10^{-3}
37914	7.4×10^{-4}	2.8×10^{-3}	10^{-3}	9.0×10^{-3}	10^{-2}	3.6×10^{-4}	10^{-4}	3.4×10^{-6}		1.8×10^{-3}	1.3×10^{-3}	10^{-3}
37915	1.4×10^{-6}	2.3×10^{-6}		5.5×10^{-4}	10^{-3}	1.5×10^{-4}	10^{-4}	1.8×10^{-6}		4.7×10^{-4}	8×10^{-6}	10^{-6}
37916	1.6×10^{-6}	2.4×10^{-6}		5.9×10^{-4}	10^{-3}	2.2×10^{-4}	10^{-4}	1.8×10^{-6}		6.5×10^{-4}	1.8×10^{-4}	10^{-4}
37917	1.1×10^{-5}	3.9×10^{-6}		5.9×10^{-4}	10^{-3}	1.1×10^{-4}	10^{-4}	1.1×10^{-6}		8.4×10^{-4}	1.3×10^{-4}	10^{-6}
37918	7.0×10^{-6}	1.5×10^{-5}		6.0×10^{-4}	10^{-3}	1.2×10^{-4}	10^{-4}	1.1×10^{-6}		4.9×10^{-3}		10^{-6}
37919	2.0×10^{-6}	3.3×10^{-6}		1.0×10^{-3}	10^{-3}	7.0×10^{-4}	10^{-4}	1.6×10^{-5}		7.3×10^{-4}	2.8×10^{-4}	10^{-3}
37920	9.6×10^{-7}	$<2\times10^{-6}$		6.6×10^{-4}	10^{-3}	9.8×10^{-5}	10^{-4}	1.5×10^{-6}		5.1×10^{-4}	9×10^{-6}	10^{-6}
37921	2.7×10^{-6}	1.5×10^{-6}		4.3×10^{-4}	10^{-3}	8.8×10^{-5}	10^{-4}	1.1×10^{-6}		3.0×10^{-4}		10^{-6}
37922	1.4×10^{-5}	$<4\times10^{-6}$		3.7×10^{-4}	10^{-3}	1.3×10^{-4}	10^{-4}	1.5×10^{-6}		3.6×10^{-4}		10^{-6}
37923	6.1×10^{-6}	1.0×10^{-6}		3.9×10^{-4}	10^{-3}	8.0×10^{-5}	10^{-4}	1.0×10^{-6}		5.5×10^{-4}		10^{-6}
37933	1.3×10^{-5}	1.3×10^{-5}		1.6×10^{-3}	10^{-3}	2.6×10^{-4}	10^{-4}	3.5×10^{-6}		1.0×10^{-3}	2.3×10^{-4}	10^{-3}
37934	1.3×10^{-5}	$<4\times10^{-6}$		5.6×10^{-4}	10^{-3}	4.5×10^{-5}	10^{-4}	1.2×10^{-5}		6.5×10^{-4}	1.3×10^{-4}	10^{-4}
37935	9.7×10^{-6}	1.1×10^{-5}		8.0×10^{-4}	10^{-3}	6.7×10^{-5}	10^{-4}	8.3×10^{-6}		7.4×10^{-4}	1.4×10^{-4}	10^{-6}
37936	5.0×10^{-6}	$<3\times10^{-6}$		2.6×10^{-4}	10^{-3}	2.6×10^{-5}		3.7×10^{-6}		3.1×10^{-4}	1.0×10^{-4}	10^{-6}
37947	1.2×10^{-5}			Trace	10^{-3}	1.5×10^{-4}	10^{-3}	2.0×10^{-5}	10^{-5}	2.2×10^{-3}		10^{-3}
37950	4.8×10^{-6}			1.3×10^{-3}	10^{-3}	5.5×10^{-4}	10^{-2}	6.9×10^{-6}	10^{-5}	2.2×10^{-3}		10^{-4}
37961	7.0×10^{-6}			1.8×10^{-3}	10^{-3}	1.1×10^{-4}	10^{-3}	7.8×10^{-6}	10^{-5}	2.1×10^{-3}		10^{-3}

LEGEND

All values g element/g dry sed.
SERL - Southeast Environmental Research Laboratory
NBS - National Bureau of Standards

NAA - Neutron Activation Analysis
ES - Emission Spectroscopy
ND - Not Detected

Table 2 Quantitative Analysis of Samples Irradiated 60 minutes (Continued)

Element	^{59}Fe		^{197}Hg			^{140}La		^{122}Sb		^{65}Zn	
Laboratory	SERL	NBS	SERL	NBS		SERL	NBS	SERL	NBS	SERL	NBS
Method / Sample	NAA	ES	NAA	NAA	ES	NAA	ES	NAA	ES	NAA	ES
37913	4.8×10^{-2}	10^{-2}	4.6×10^{-4}	3.5×10^{-4}		1.9×10^{-6}		7.3×10^{-5}		7.1×10^{-3}	10^{-4}
37914	3.9×10^{-2}	10^{-2}	1.0×10^{-3}	1.1×10^{-3}	10^{-4}	2.9×10^{-6}		Trace		6.9×10^{-4}	10^{-4}
37915	4.1×10^{-2}	10^{-2}	ND	<5 $\times10^{-7}$		6.5×10^{-6}		1.2×10^{-6}		ND	
37916	3.7×10^{-2}	10^{-2}	6 $\times10^{-6}$	9 $\times10^{-6}$		4.6×10^{-6}		2.6×10^{-6}		Trace	10^{-4}
37917	3.8×10^{-2}	10^{-2}	ND	<6 $\times10^{-7}$		8.2×10^{-6}		6.7×10^{-6}		ND	10^{-4}
37918	3.0×10^{-2}	10^{-2}	Trace	2 $\times10^{-6}$		8.5×10^{-6}		2.0×10^{-6}		ND	
37919	1.1×10^{-1}	10^{-2}	1.0×10^{-6}	6 $\times10^{-6}$		4.0×10^{-6}		4.7×10^{-6}		1.5×10^{-3}	10^{-4}
37920	4.6×10^{-2}	10^{-2}	ND	<5 $\times10^{-7}$		4.3×10^{-6}		4.8×10^{-7}		ND	
37921	2.2×10^{-2}	10^{-2}	ND	<8 $\times10^{-7}$		6.0×10^{-6}		9.1×10^{-7}		ND	
37922	3.4×10^{-2}	10^{-2}	2.1×10^{-4}	2.2×10^{-4}	10^{-4}	6.7×10^{-6}		3.7×10^{-7}		ND	
37923	2.5×10^{-2}	10^{-2}	ND	<7 $\times10^{-7}$		6.8×10^{-6}		8.1×10^{-7}		ND	
37933	5.8×10^{-2}	10^{-2}	Trace	<1 $\times10^{-6}$		9.8×10^{-6}		1.7×10^{-6}		ND	10^{-4}
37934	3.4×10^{-2}	10^{-2}	ND	2 $\times10^{-6}$		8.2×10^{-6}		5.2×10^{-7}		ND	10^{-4}
37935	1.8×10^{-2}	10^{-2}	6.3×10^{-7}	2 $\times10^{-6}$		4.3×10^{-6}		1.3×10^{-6}		Trace	10^{-4}
37936	8.4×10^{-2}	10^{-2}	4.8×10^{-6}	3 $\times10^{-6}$		1.9×10^{-6}		4.6×10^{-7}		Trace	
37947	4.5×10^{-2}	10^{-2}				3.5×10^{-6}		Trace		Trace	
37950	1.8×10^{-2}	10^{-2}				6.6×10^{-6}		1.01×10^{-6}		ND	
37961	3.5×10^{-2}	10^{-2}				6.0×10^{-6}		1.2×10^{-6}		ND	

LEGEND

All values g element/g dry sed.
SERL - Southeast Environmental Research Laboratory
NBS - National Bureau of Standards

NAA - Neutron Activation Analysis
ES - Emission Spectroscopy
ND - Not Detected

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